# Relationship between Satellite-Derived Snow Cover and Snowmelt-Runoff Timing and Stream Power in the Wind River Range, Wyoming

Dorothy K. Hall[1], James L. Foster[1], Nicolo E. DiGirolamo[2]

and

George A. Riggs[2]

[1]Laboratory for Hydrospheric and Biospheric Processes, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA

[2]SSAI, Lanham, MD 20706 USA

Key words: Wind River Range, MODIS, seasonal snow cover, streamflow runoff

## Abstract

Earlier onset of springtime weather including earlier snowmelt has been documented in the western United States over at least the last 50 years. Because the majority (>70%) of the water supply in the western U.S. comes from snowmelt, analysis of the declining spring snowpack (and shrinking glaciers) has important implications for streamflow management. The amount of water in a snowpack influences stream discharge which can also influence erosion and sediment transport by changing stream power, or the rate at which a stream can do work such as move sediment and erode the stream bed. The focus of this work is the Wind River Range (WRR) in west-central Wyoming. Ten years of Moderate-Resolution Imaging Spectroradiometer (MODIS) snow-cover, cloud-gap-filled (CGF) map products and 30 years of discharge and meteorological station data are studied. Streamflow data from six streams in the WRR drainage basins show lower annual discharge and earlier snowmelt in the decade of the 2000s than in the previous three decades, though no trend of either lower streamflow or earlier snowmelt was observed using MODIS snow-cover maps *within* the decade of the 2000s. Results show a statistically-significant trend at the 95% confidence level (or higher) of increasing weekly maximum air temperature (for three out of the five meteorological stations studied) in the decade of the 1970s, and also for the 40-year study period. MODIS-derived snow cover (percent of basin covered) measured on 30 April explains over 89% of the variance in discharge for maximum monthly streamflow in the decade of the 2000s using Spearman rank correlation analysis. We also investigated stream power for Bull Lake Creek Above Bull Lake from 1970 to 2009; a statistically-significant trend toward reduced stream power was found (significant at the 90% confidence level). Observed changes in streamflow and stream power may be related to increasing weekly maximum air temperature measured during the 40-year study period. The strong relationship between percent of basin covered and streamflow indicates that MODIS data is useful for predicting streamflow, leading to improved reservoir management.

## Introduction and Background

Earlier onset of spring-like weather has been documented in the western United States since at least the late 1970s; the warm episodes are related to larger-scale atmospheric conditions across North America and the North Pacific (Cayan et al., 2001; Mote, 2003; Mote et al., 2005). In addition, most of the glaciers throughout western North America have generally been losing mass since the Little Ice Age ended in the mid-to-late 1800s (PDX, 2010a); Cheesbrough et al., 2009; Moore et al., 2009). Mean annual temperatures over northwestern North America have increased by ~1 – 2°C (Karl et al., 1993; Dettinger and Cayan, 1995) since the 1940s, with perhaps a greater increase from the mid-1960s to the early 1990s (Naftz et al., 2002).

In many high-elevation streams in the western U.S. there has been a reduction in the portion of annual stream discharge occurring during spring and early summer, that fraction of the streamflow attributable to spring snowmelt (see for example, Dettinger and Cayan, 1995; Cayan et al., 2001). The fraction of annual streamflow that runs off during late spring and summer has declined by 10 – 25% since the 1950s due to warmer winter and spring weather (Cayan et al., 2001), and snowmelt runoff arrives 1 – 3 weeks earlier in many mountain basins in the western U.S. (Stewart et al., 2005; Lundquist et al., 2009). Warmer air temperatures also may be associated with less total snow-cover extent (see for example, Foster et al., 1983; Cohen and Fletcher, 2007) especially at the lower elevations. In much of the western U.S., and specifically in western Wyoming where the Wind River Range (WRR) is located, the date of spring snowmelt onset is earlier by up to or greater than 20 days as compared to the mid-20th Century (USGS, 2005). Because the majority of the water supply in the western U.S. comes from snowmelt (and to a much-lesser extent, from glacier melt), analysis of the declining snowpack and shrinking glaciers has important implications for streamflow management (Mote, 2003; USGS, 2005; Westerling et al., 2006).

In addition to the influence of snow amount and melt timing on water resources, stream power is also influenced by the mountain snowpack. Stream power influences the amount and size of sediment transport and thus the ability of the stream to erode the stream bed. Stream power (Bagnold, 1977; Ferguson, 2005) is the rate of energy dissipation against the bed and banks of a river or stream. [Effective discharge is another measure of interest but was not investigated in this study. Computations of effective discharge can provide a basis for comparing the geomorphic work of streams in different watersheds (Crowder and Knapp, 2005).]

The objective of this work is to investigate the relationship between air temperature and snow cover in the WRR from 2000 through 2009, and to address the influence of changing snowpack conditions on snowmelt timing and stream power. We use 10 years of Moderate-Resolution Imaging Spectroradiometer (MODIS) snow-cover maps of the WRR along with ancillary data (a digital-elevation model, streamflow data and air-temperature data). Our focus is on the lowest elevations of the WRR (2500 – 3000 m) because that is where changes in snowmelt timing have already been observed (e.g., Mote, 2003).